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US 4298087 A US 4168761 A

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(54) **Loud speaker enclosure and tunable audio reproduction apparatus**

(57) An acoustic transmission line speaker enclosure 10, has concentric cylindrical structures 20, 30 which establish acoustic coupling between a rear-travelling sound wave and a surrounding air mass. Inherent rigidity or high bending resistance of the cylindrical structures 20, 30 allows use of very thin walled cylinders without a massive and large overall enclosure. An audio amplifier 218, 220, 230, 232 tunable to the resonant frequency of a listening room 212 removes very low narrow frequency band components of an audio signal produced by the speaker enclosures 10a, 10b and the listening room 212 cavity resonance is measured by injecting a frequency-varying sound wave into the listening room 212 while detecting peak sound energy within the room, the filter then serves to eliminate frequencies associated with listening room cavity resonance from the audio signal by way of a filter 220 associated with the amplifier.

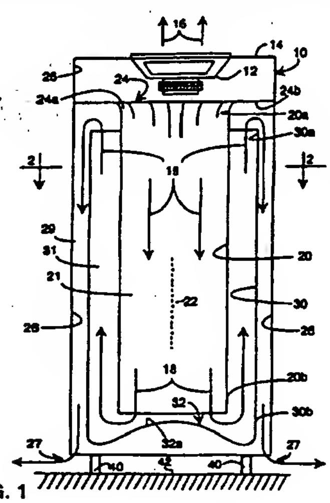

FIG. 1

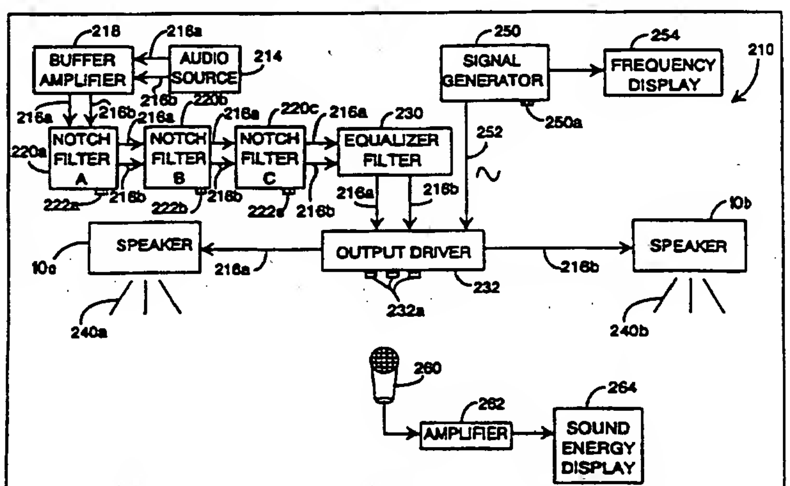

FIG. 7

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print incorporates corrections made under Section 117(1) of the Patents Act 1977.

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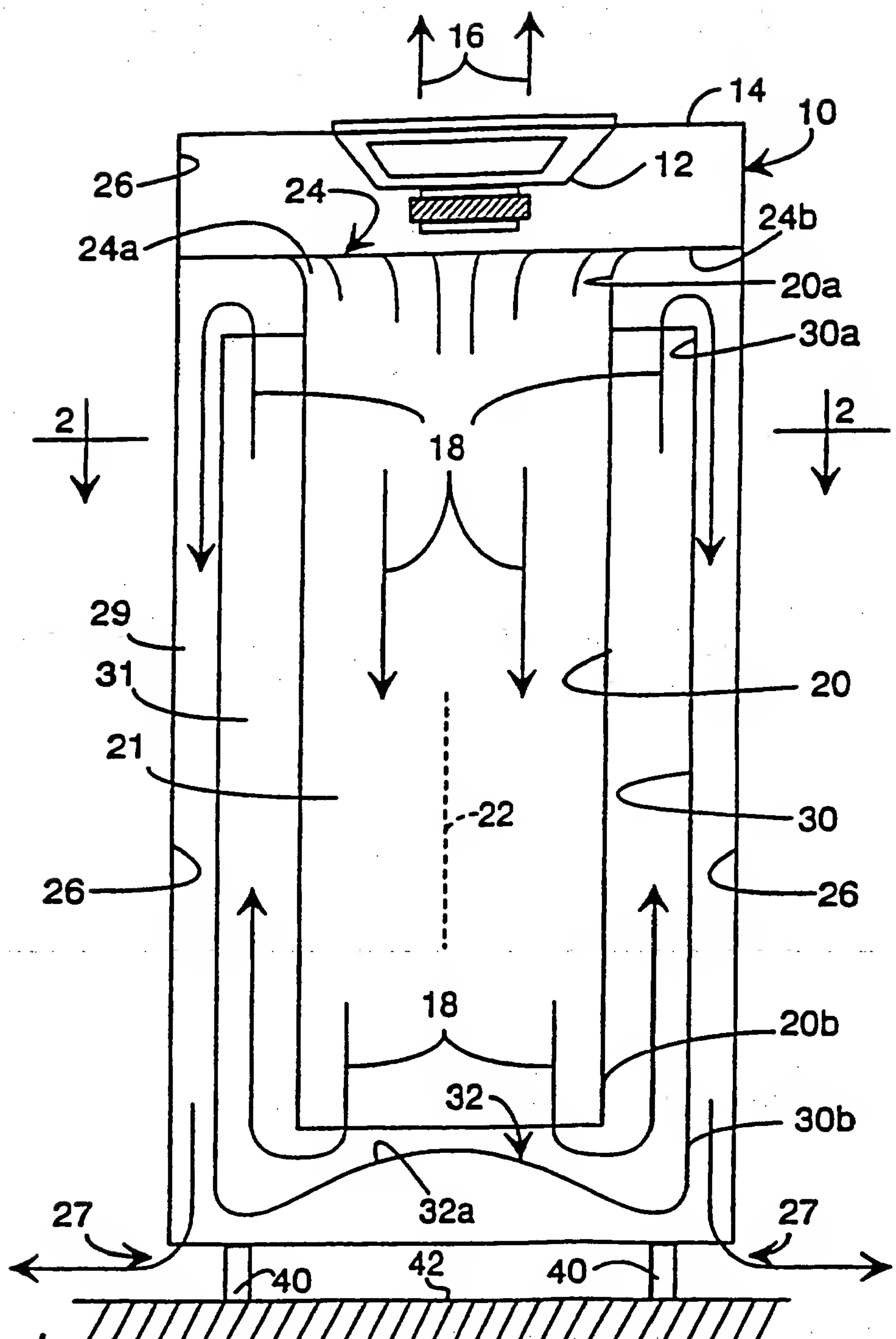
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14
10
12
26
24
24a
24b
20a
30a
2
2
18
29
20
31
21
22
30
26
26
18
20b
32
30b
27
32a
27
42
40
40

FIG. 1

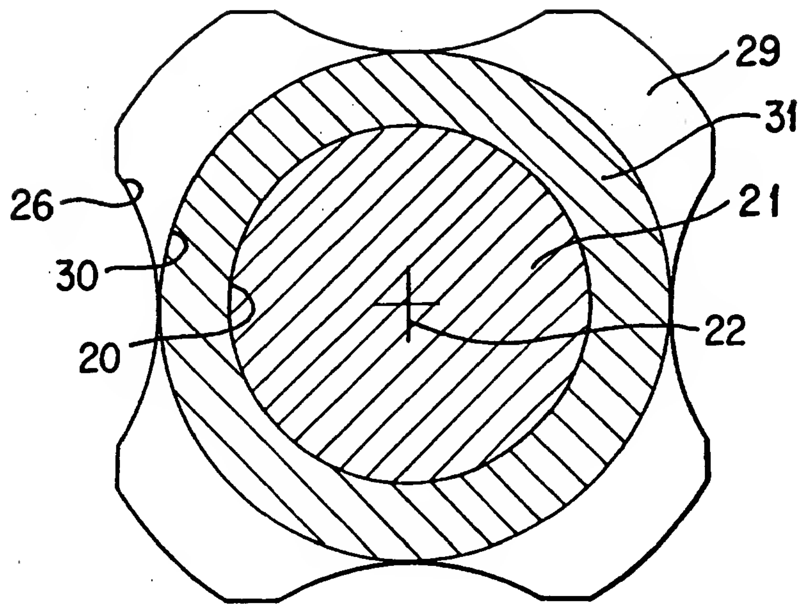
29
31
26
21
30
22
20

FIG. 2

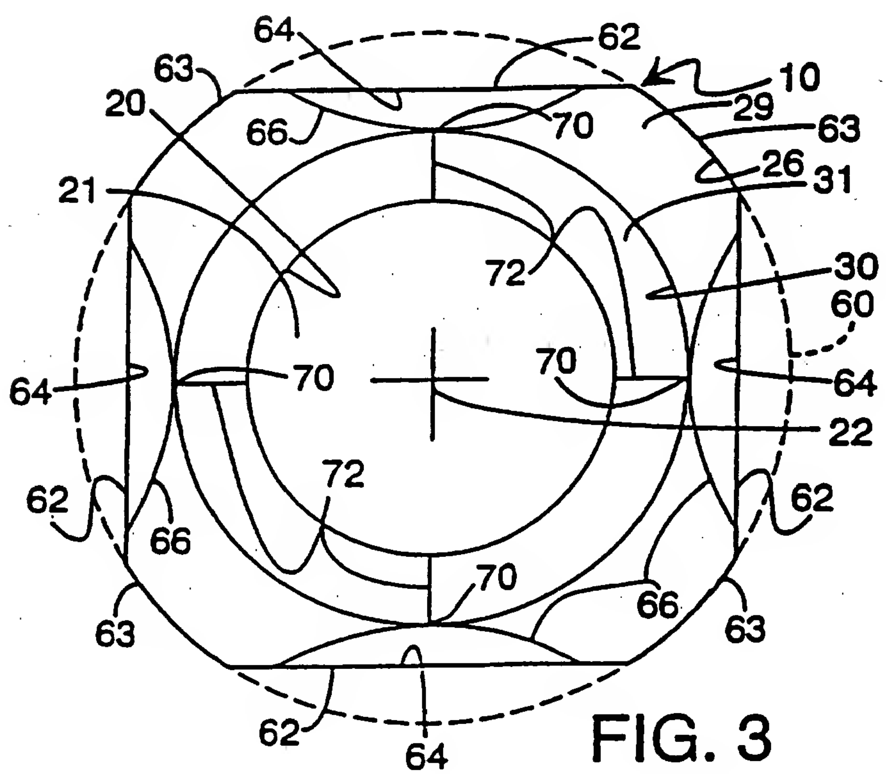
64
62
63
10
20
29
66
70
63
26
21
31
72
30
60
70
64
70
64
22
72
62
62
66
70
66
63
63
62
64

FIG. 3

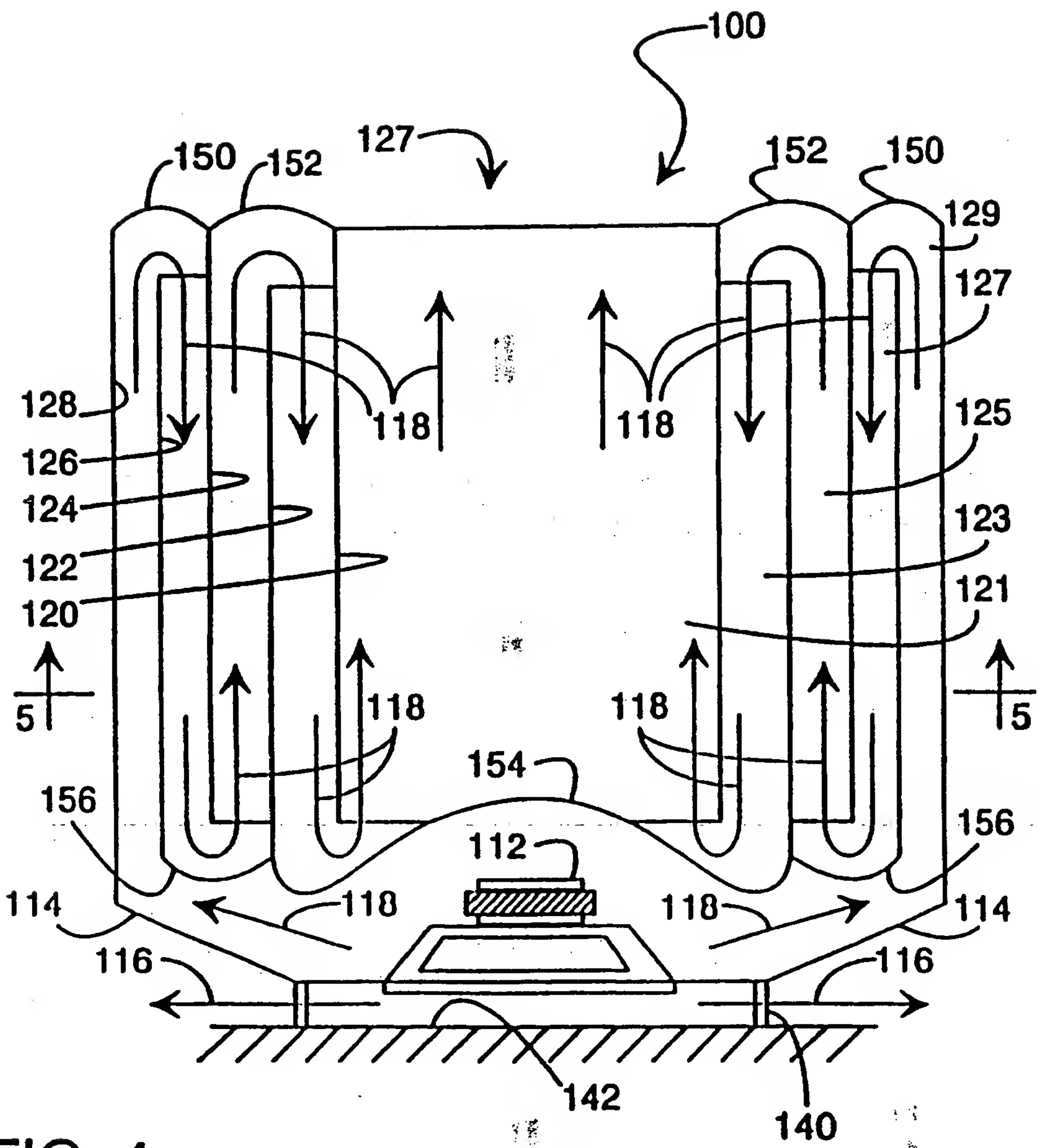
100
127
150
152
152
150
129
127
128
118
118
125
126
124
123
122
121
120
5
5
118
118
154
156
156
112
114
118
118
114
116
116
142
140

FIG. 4

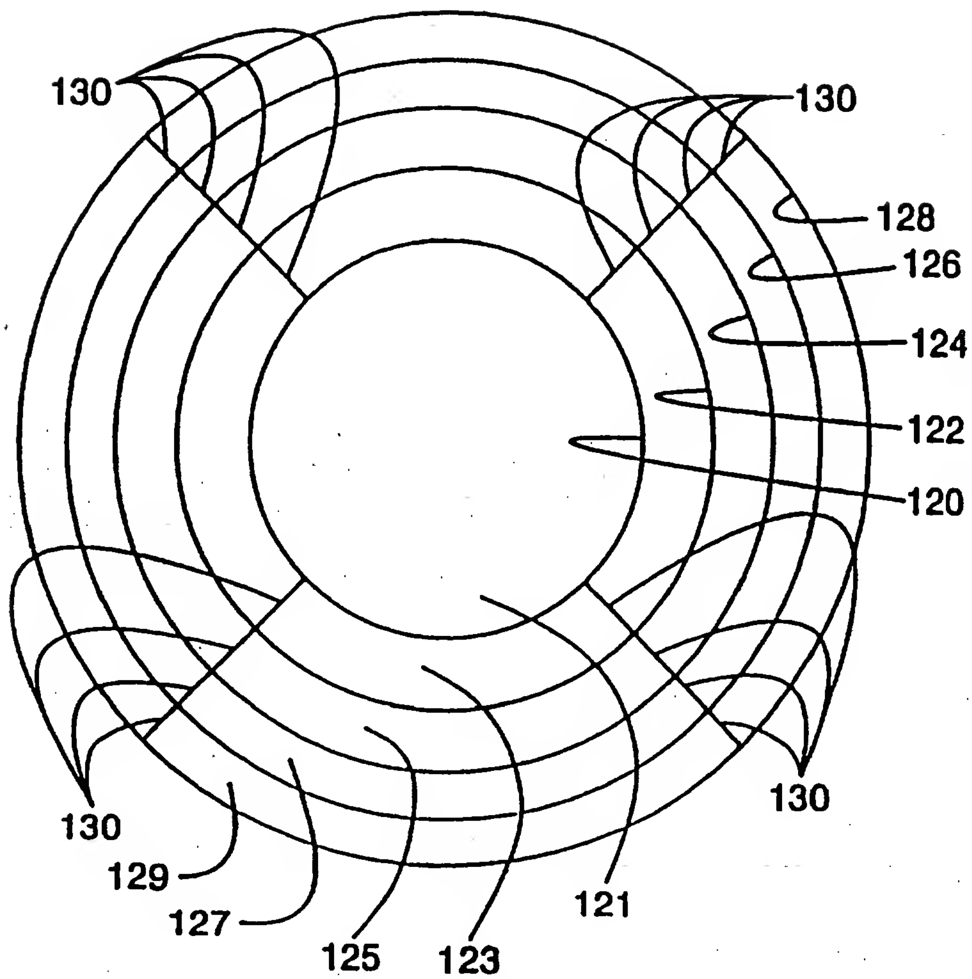

FIG. 5

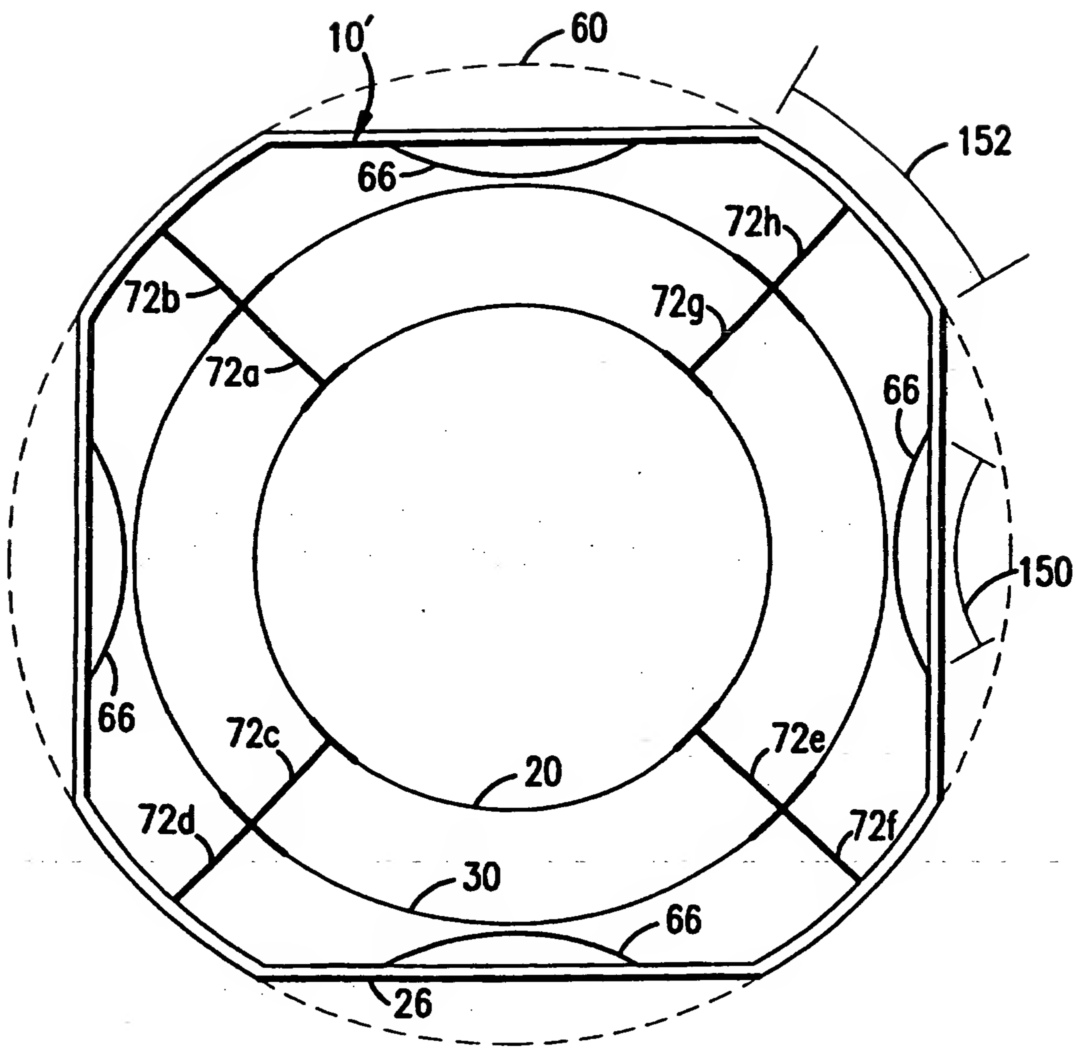

FIG.6

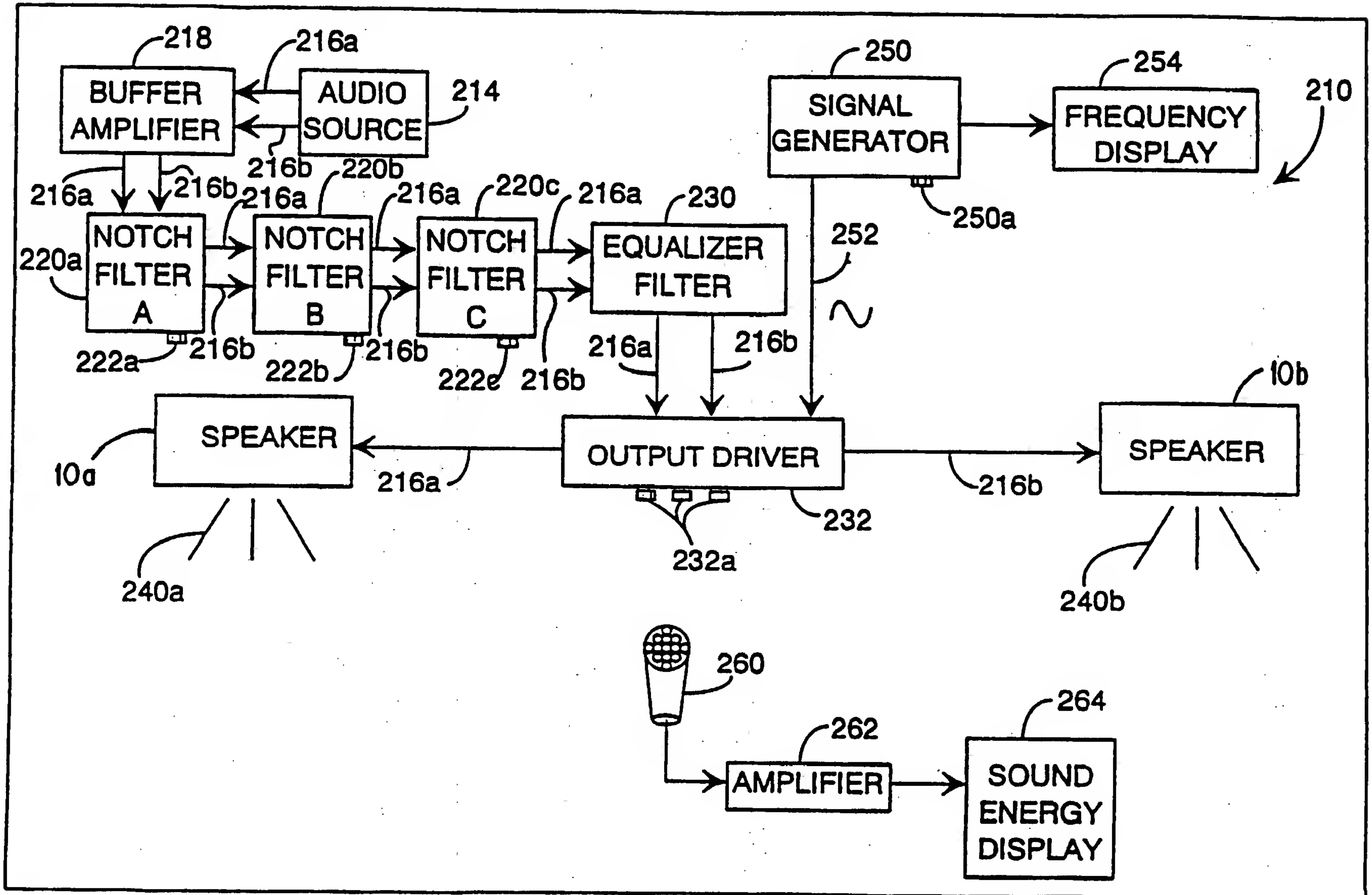
BUFFER AMPLIFIER
218
216a
AUDIO SOURCE
214
216b
220b
216a
216b
216a
NOTCH FILTER A
220a
NOTCH FILTER B
NOTCH FILTER C
220c
216a
EQUALIZER FILTER
230
216b
222a
222b
222e
SIGNAL GENERATOR
250
250a
FREQUENCY DISPLAY
254
210
252
216a
216b
SPEAKER
10a
OUTPUT DRIVER
232
232a
SPEAKER
10b
240a
240b
260
AMPLIFIER
262
SOUND ENERGY DISPLAY
264
212

FIG. 7

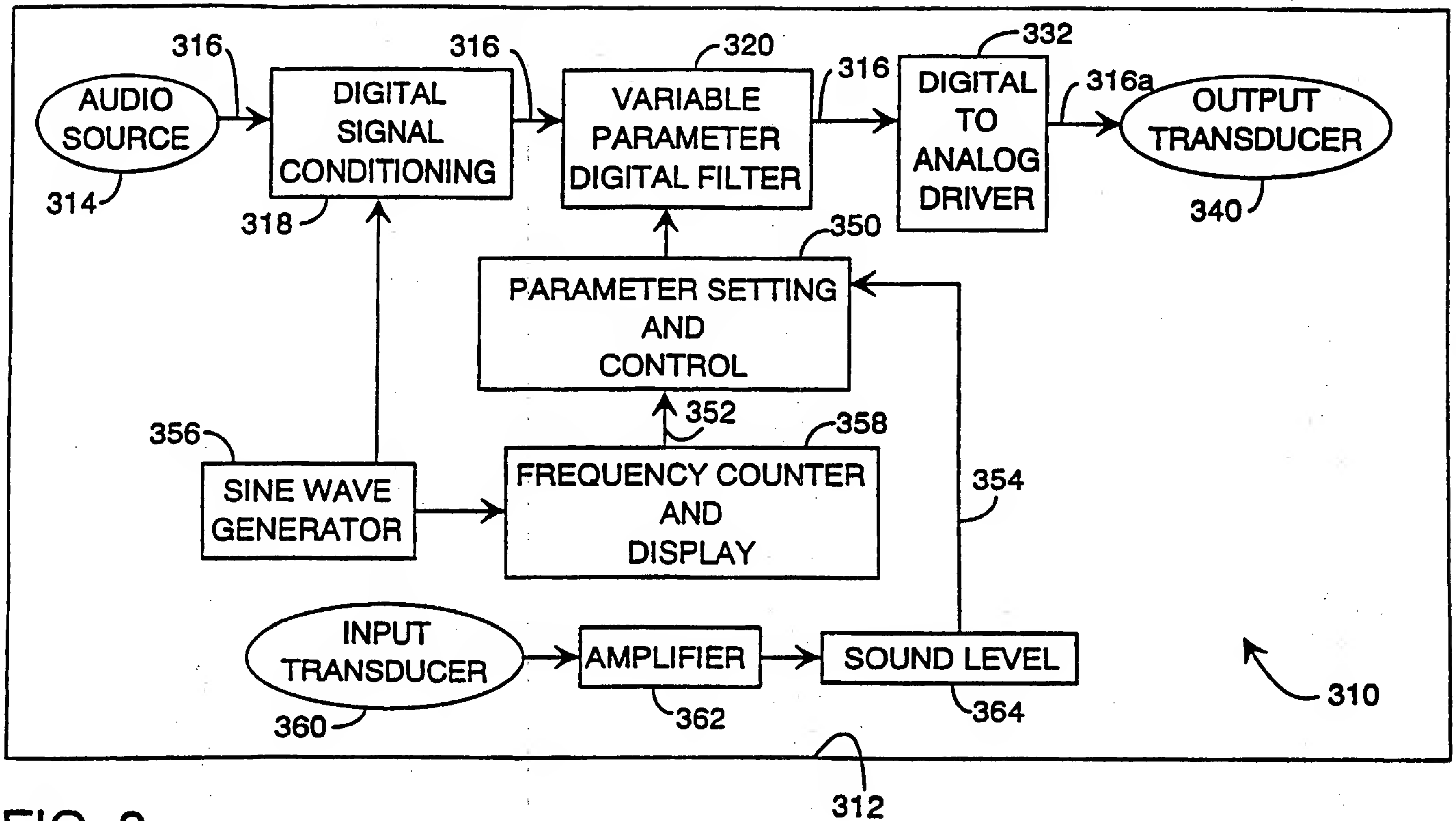
AUDIO SOURCE
314
316
DIGITAL SIGNAL CONDITIONING
318
316
VARIABLE PARAMETER DIGITAL FILTER
320
316
DIGITAL TO ANALOG DRIVER
332
316a
OUTPUT TRANSDUCER
340
PARAMETER SETTING AND CONTROL
350
352
FREQUENCY COUNTER AND DISPLAY
358
SINE WAVE GENERATOR
356
354
INPUT TRANSDUCER
360
AMPLIFIER
362
SOUND LEVEL
364
310
312

FIG. 8

LOUD SPEAKER ENCLOSURE AND TUNABLE AUDIO REPRODUCTION APPARATUS

The present invention relates generally to sound reproduction equipment, and particularly to loud speaker enclosures and to tunable audio reproduction equipment arranged particularly for use with such loud speaker enclosures.

Audio reproduction systems continue to evolve toward higher quality sound reproduction. Inherent non-linearity, i.e., variation in sound energy as a function of sound wavelength, continues to improve through research and development. From audio recording to audio reproduction, vast improvement in quality of equipment benefits the discerning listener. Unfortunately, challenges remains in the context of distortion and frequency response for most audio equipment, especially at low frequency or bass wavelengths. Even highly advanced equipment suffers at extreme low frequencies in faithfully reproducing a linear sound presentation.

A high quality musical sound wave emerges from a loud speaker diaphragm coupled acoustically to a listening room, and a

corresponding inverse-phase sound wave emerges from the rear of the speaker diaphragm. This rear-traveling sound wave, upon eventually being coupled to the surrounding air mass, introduces non-linearity in the otherwise high quality sound provided within the room by the front-traveling sound wave. Solutions have evolved, but not always proportionately for sound quality improvement in relation to expense.

A traditional cone diaphragm speaker pushes air forward out of the speaker enclosure in producing sound waves within a listening room. Sound waves emanating from the front and rear of the speaker diaphragm are complimentary, i.e., 180 degrees in phase relationship. Accordingly, coupling the forward traveling and rearward traveling sound waves within a common listening room can introduce non-linearity in sound presentation due to sound wave interference and cancellation. Ideally, such rear-traveling sound waves couple to a separate listening chamber, thereby avoiding sound wave interference and cancellation. For example, mounting speaker diaphragms within walls sends front-traveling waves to a first listening room and rear-traveling waves to a second listening room. Unfortunately, elaborate wall-mounted speaker systems are impractical for most listeners.

The traditional mechanism delivering sound presentation within a listening room is a speaker within an enclosure. The speaker diaphragm couples directly at its front surface to the listening room, and at its rear surface to the interior of the

enclosure. Unfortunately, high quality sound reproduction requires venting or release from the enclosure of the rear-traveling sound waves, i.e., eventually the rear-traveling sound waves must exit the enclosure. The rear-traveling sound waves, upon emanating from the enclosure, preferably introduce little or no interference or sound wave cancellation relative to the front-traveling sound waves.

Acoustic transmission line speakers manage rear-traveling sound waves within a speaker enclosure. Generally, a transmission line speaker enclosure provides acoustic coupling from the rear surface of the speaker diaphragm to the listening room along a transmission line or chamber of given length and cross sectional area. Acoustic transmission line length is a function of the wavelength of a particular sound frequency, e.g., speaker resonance. Cross sectional area corresponds to the effective surface area of the sound source, e.g., effective surface area of the speaker diaphragm.

A variety of acoustic transmission line speakers are known and commercially available. Unfortunately, due to the significant chamber length required in most acoustic transmission line speakers, i.e., those directed to management of very low frequency sound waves, acoustic transmission line speakers have evolved into large and massive structures. The acoustic transmission line can be "folded" or routed within the enclosure

in a labyrinth to establish the required length within an overall box-like shape. Panels, typically wood, within the enclosure form the required acoustic transmission line or chamber with appropriate cross sectional area therealong. To resist deformation of the panels in response to sound pressure within the acoustic transmission line, such panels must be of sufficient structural integrity, i.e., thickness, to maintain rigidity against sound wave pressure. The combination of thick panel structures forming the acoustic transmission line as a folded labyrinth within the speaker enclosure results in massive and large overall volume speaker enclosures.

The subject matter of the present invention addresses this aspect of transmission line speaker enclosures by providing a transmission line speaker enclosure having an acoustic transmission line of appropriate length and cross section, but not requiring a large volume, massive speaker enclosure structure.

A reverberating sound wave, established by surrounding walls, floor, and ceiling, also brings interference relative to other sound waves within the listening room. This interference introduces non-linearity in the otherwise high quality sound provided at the loud speaker. Sound absorbent material in the listening room and elaborate tuning schemes attempt to minimize such non-linearity, but such methods and apparatus do not always

proportionately improve sound quality in relation to the magnitude of expense required.

Cavity resonance in a listening room provides a significant source of reverberation interference degrading a high quality sound presentation. Room cavity resonance operates at a given fundamental frequency and associated harmonic frequencies. Across a range of typical room sizes, the fundamental resonate frequency falls in an audible frequency band. Due to cavity resonance, sound energy at the fundamental frequency does not dissipate as do other sound frequencies. Sound pressure, developed at the fundamental and harmonic frequencies, tends to build. The listener perceives a relatively louder sound at the resonant and harmonic frequencies. In other words, sound pressure tends to build excessively at the fundamental and harmonic frequencies within a given listening room and becomes, for the discriminating listener, an annoying departure from linear sound presentation.

Unfortunately, cavity resonance for a given listening room varies as a function of air density, room furnishings, or barometric conditions. Predicting narrow band cavity resonance in a given listening room becomes impossible. Cavity resonance can be as narrow as one hertz (Hz) in some listening rooms. Accordingly, an attempt to anticipate cavity resonance and filter such narrow fundamental frequency bands fails due to the narrow

and unpredictable character of the fundamental and harmonic resonant frequencies.

The present invention seeks to provide an apparatus and method relating to loud speaker generated signals having advantages over known such apparatus and methods.

According to one aspect of the present invention there is provided an acoustic transmission line speaker enclosure comprising a speaker driver mounting site defining front and rear directions, a first cylinder positioned relative to said speaker mounting site to receive at a first end a rear-travelling sound wave and to emanate at a second end said rear-travelling sound wave, a second cylinder concentric to and relatively larger than said first cylinder, an inner radius of said second cylinder being selected relative to an outer radius of said first cylinder to establish a space between said first and second cylinders of cross-sectional area substantially equal to an inner cross-sectional area of said first cylinder, a first end of said second cylinder being adjacent said first end of said first cylinder and a second end of said second cylinder being adjacent said second end of said first cylinder, and a cap at said second end of said second cylinder directing said rear-travelling sound wave from said first cylinder into said space between said first and second cylinders while maintaining therealong a cross-sectional area substantially equal to that of said space.

An acoustic transmission line speaker enclosure according to one embodiment of the present invention includes a speaker driver mounting site defining front and rear directions. A first cylinder is positioned relative to the speaker mounting site to receive at a first and a rear-travelling sound wave and to emanate at a second end the rear-travelling sound wave. A second cylinder concentric to and relatively larger than the first cylinder surrounds the first cylinder. A cap at the second end of the second cylinder directs the rear-travelling sound wave from the first cylinder into a space between the first and second cylinders.

Additional cylinders may be added in concentric relation. Each cylinder radius creates an acoustic space between itself and a next-inner cylinder and having a cross sectional area equal to the cross sectional area of the central cylinder, the desired cross sectional area of the acoustic transmission line speaker. Cylinder lengths vary to establish a desired acoustic transmission line length.

According to another aspect, a transmission line speaker enclosure under the present invention includes a plurality of sleeves arranged concentrically. A central one of the sleeves defines an associated acoustic space therein with a given cross sectional area. Each remaining sleeve defines an associated acoustic space between itself and a next smaller one of the sleeves. Each of the acoustic spaces are equal in cross sectional area to the given cross sectional area. Caps couple edges of alternating ones of the sleeves to establish, via the acoustic spaces, an acoustic transmission line within the enclosure.

According to yet another aspect of the present invention, an audio reproduction system listening room tuning component receives an audio signal and provides a filtered audio signal. The tuning component includes a variable frequency sound source applicable to the listening room and including a frequency indicator. A sound input transducer measures and indicates sound energy within the listening room. A filter receives the audio signal and provides the filtered audio signal. The filter includes at least one control dictating a frequency band filtered and calibrated relative to the frequency indicator. By injecting a range of frequencies, including listening room cavity resonate frequencies, a peak value in sound energy indicates cavity resonate frequencies to be applied as control to the filter.

In accordance with still another aspect of the present invention there is provided in audio reproduction system tunable to a bounded listening area, the system comprising an audio source providing a first audio signal, at least one variable frequency notch filter, said notch filter including a

control dictating a frequency band filtered thereby, said notch filter receiving said first audio signal, applying a frequency filter function thereto, and providing a filtered audio signal, a second audio source providing a second audio signal as a variable frequency audio signal, audio transducers receiving an amplified audio signal and injecting corresponding sound waves into the listening area, a sound energy detection device responsive to sound waves in the listening area and an audio driver receiving said filtered audio signal and said second audio signal whereby said system is tuned to the listening area by first injecting said second audio signal into said area across a range of frequencies, monitoring said sound energy level device to determine a listening area cavity resonant frequency, and applying a representation of said resonate frequency as a control to said notch filter whereupon application of said filtered audio signal to said listening room excludes frequencies at said resonant frequency.

According to a further aspect of the present invention, a method of tuning an audio system to a listening room is provided which begins by detecting a cavity resonant frequency of the listening room and then adjusting a filter to the detected resonant frequency to filter an audio signal at the resonant frequency. Thereafter, the method applies the filtered audio signal to sound transducers within the room.

The subject matter of the present invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. However, both the organization and method of operation of the invention, together with further advantages and objects thereof, may best be understood by reference to the following description taken with the accompanying drawings wherein like reference characters refer to like elements.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings in which:

FIG. 1 illustrates schematically a multi-concentric transmission line speaker enclosure embodying the present invention;

FIG. 2 illustrates cross sectional areas of the acoustic transmission line provided by the enclosure of FIG. 1 as taken along lines 2-2 of FIG. 1;

FIG. 3 illustrates a sectional view of the enclosure of FIG. 1, as taken along lines 2-2 ;

FIG. 4 illustrates a second embodiment of a multi-concentric transmission line speaker of the present invention;

FIG. 5 illustrates a cross sectional view of the speaker enclosure of FIG. 4 as taken along lines 5-5 of FIG. 4 ;

FIG. 6 illustrates further structural details of the speaker enclosure of FIG. 1 ;

FIG. 7 illustrates an analog audio amplifier according to an embodiment of the present invention tunable to a given listening room ; and

FIG. 8 illustrates a digital audio amplifier according to another embodiment of the present invention tunable to a given listening room.

FIG. 1 illustrates schematically a three cylinder acoustic transmission line speaker enclosure 10. Externally, enclosure 10

presents a top wall 14, sidewalls 26, and a bottom opening 27. A speaker driver 12 is mounted in top wall 14. Driver 12 emits a front sound wave 16, i.e., externally and upward relative to enclosure 10, and a rear sound wave 18. Rear sound wave 18 travels within enclosure 10 and eventually exits bottom opening 27. A central cylinder 20 rests concentrically relative to a central axis 22 of enclosure 10. An upper end 20a of central cylinder 20 opens as a flange 24 extending radially outward to sidewalls 26 of enclosure 10. The rear sound wave 18 enters a space 21 within central cylinder 20 through end 20a by way of upper surface 24a of flange 24. The lower end 20b of central cylinder 20 remains open.

A second cylinder 30, of radius larger than central cylinder 20, also lies concentric to central axis 22. Thus, central cylinder 20 lies generally within and concentric to second cylinder 30. Upper end 20a and flange 24 extend beyond upper end 30a of second cylinder 30 and toward driver 12. The perimeter of upper end 30a of cylinder 30 remains open. A cap 32 covers the lower end 30b of second cylinder 30, but at a given distance from the open lower end 20b of central cylinder 20. As rear sound wave 18 travels downward within space 21 of cylinder 20 and out lower end 20a, sound wave 18 eventually encounters the inner surface 32a of cap 32. Cap 32 directs sound wave 18 from within inner cylinder 20 to space 31 of second cylinder 30. In particular, cap 32 directs sound wave 18 into and upward along space 31 between inner cylinder 20 and outer cylinder 30. As

illustrated in FIG. 1, the inner surface 32a includes a convex central portion and concave peripheral portion. Such contouring may be refined mathematically according to a desired guide path for sound wave 18 from central cylinder 20 into second cylinder 30. In addition, cap 32 must be spaced appropriately from end 20b of cylinder 30 to maintain the desired cross sectional area in transition from space 21 to space 31.

Sound wave 18 then travels within space 31 upward along the perimeter of cylinder 30 and eventually reaches the upper end 30a of cylinder 30. Outer sidewalls 26 may be formed as a cylinder also concentric to axis 22. Under the particular embodiment illustrated herein the outer structure employed is not a cylinder, but does provide a space 29 between the exterior of second cylinder 30 and sidewalls 26. The assembly of central cylinder 20 and second cylinder 30 rests concentrically within enclosure 10, i.e., centered within sidewalls 26 of enclosure 10. Under the particular embodiment illustrated herein, sidewalls 26 define in cross section a "demi-square" shape as described more fully hereafter.

In either case, sidewalls 26 define a space 29 between the exterior surface of second cylinder 30 and the inner surface of sidewalls 26. Space 29 is open to the listening room via bottom opening 27 of enclosure 10. As sound wave 18 travels past upper end 30a of second cylinder 30, sound wave 18 encounters the

undersurface 24b of flange 24. Undersurface 24b redirects sound wave 18 downward along the inner surface of sidewalls 26, i.e., in space 29 between second cylinder 30 and sidewalls 26. Sound wave 18 eventually emerges from the bottom opening 27 of enclosure 10. Legs 40 couple to sidewalls 26 and provide clearance between bottom opening 27 and a floor 42 upon which enclosure 10 rests.

FIG. 2 illustrates in cross section the spaces 21, 31, and 29 within enclosure 10 and providing uniform acoustic transmission line cross sectional area. The cross section of space 21 is circular and corresponds to the effective displacement area for speaker driver 12. The cross sectional area for space 31, i.e., between cylinder 20 and cylinder 30, is annular and equal to the cross sectional area of space 21. Space 29 has a cross sectional area also equal to that of spaces 21 and 31. While an annular cross section for space 29 would result from use of a section of cylinder in forming sidewalls 26, this particular embodiment of the present invention employs a structure having a "demi-square" shape.

FIG. 3 illustrates schematically the structure of enclosure 10 as taken along lines 2-2 of FIG. 2, but detailing the "demi-square" shape provided by sidewalls 26. In FIG. 3, the "demi-square" cross sectional shape for exterior walls 26 begins with a cylinder 60. Cylinder 60 is made "demi-square" by taking four

sectors 62, each parallel to central axis 22. Each sector thereby defines a flat panel wall 64 coupled to remaining adjacent portions 63 of cylinder 60. At the interior surface of each flat panel wall 64, a curved plate 66, having sufficient bending resistance, attaches. In this manner, the curved plates 66 introduce sufficient bending resistance for the otherwise planar walls 64. Also indicated in FIG. 3, curved plates 66 attach to the exterior of cylinder 30 at support points 70 to aid in support for the assembly of cylinders 20 and 30. Further, support arms 72 couple the exterior surface of cylinder 20 and the interior surface of cylinder 30 to further aid in structural support and rigidity.

Thus, enclosure 10 provides an acoustic transmission line coupling back sound wave 18 to the air chamber external of enclosure 10. The following formula calculates an acoustic transmission line length (L) as function of sound wave length (λ):

$$L=\frac{\lambda}{4}$$

The required minimum length of the acoustic transmission line for enclosure 10 should be calculated at a lowest frequency of audio sound to be reproduced by speaker driver 12. For example, to extend the response smoothly to a 30 Hz sound wave

18, the minimum length of the transmission line is L=2.886 meters **(112.8 inches).** As may be appreciated, the multi-concentric cylinder architecture of enclosure 10 supports simple modification in acoustic transmission line length by simply varying the length of the various cylindrical structures.

In addition to length, an acoustic transmission line must provide along each portion of its path a cross sectional area equal to the sound wave carried therein, i.e., substantially equal to the cross sectional area of speaker driver 12. Speaker driver manufacturers typically provide as a specification the effective area of displacement provided by a given speaker driver. By appropriately selecting the radius of each cylindrical structure, a uniform cross sectional area results along the entire length of the acoustic transmission line.

The cross-sectional area of the interior of central cylinder 20 corresponds to the displacement area of speaker driver 12, designated A1 herein. The following formula calculates a radius for the inner surface of central cylinder 20 relative to axis central 22:

$$\sqrt{\frac{A1}{\pi}}$$

Central cylinder 20 wall thickness, i.e., difference between

inner surface and outer surface radii relative to central axis 22, takes into account material used and a desired high bending resistance. Such thickness varies across design and cost of manufacture criteria, but under the present invention is generally minimized due to the inherent high bending resistance provided by a cylindric body such as central cylinder 20. More particularly, the high bending resistance of the cylinder structure as used in multi concentric cylindric transmission line speaker enclosure under the present invention allows very thin cylinder walls.

A woofer speaker can range from six to twelve inches in diameter. For such speakers, wall thickness for cylinders 20 and 30 may be as little as 0.5 to 1.5 mm thickness of aluminum material. Such structure, though extremely thin, is strong enough to resist deformation due to vibration induced by the impact of sound pressure therein. A similar result, i.e., very thin wall thickness, may be obtained by use of plastic materials.

Use of aluminum and plastics in forming a multi-concentric acoustic transmission line simplifies manufacture relative to use of alternative, and traditional, material such as wood. Furthermore, aluminum and plastic materials can be recycled as an environmental and ecologically friendly feature of the present invention. For example, an aluminum cylinder may be compared to a woodpanel-formed duct. For an inside diameter of 300 mm and

wall thickness of 0.5 mm, an aluminum cylinder deforms radially approximately 0.14 mm in response to two atmospheres of pressure within. A woodpanel-formed duct having the same interior cross-section, e.g., a 266 mm square interior, requires a wall thickness of approximately 12 mm to sustain a 0.18 mm displacement in response to two atmospheres pressure within. Thus, for approximately the same resistance to deformation in response to air pressure, the cylindric structure allows significantly thinner walls, i.e., a woodpanel-formed duct has walls approximately 24 times thicker than that of the aluminum cylinder.

An outside radius for cylinder 20, i.e., inner radius plus cylinder 20 wall thickness, may be designated R1 and the inner radius of second cylinder 30 calculated as follows:

$$\sqrt{\frac{R1^2+A1}{\pi}}$$

Second cylinder 30 wall thickness establishes a desired bending resistance taking into account material used. Second cylinder 30 outer radius may be designated R2 and the inner radius for a next concentric cylinder calculated as follows:

$$\sqrt{\frac{R2^2+A1}{\pi}}$$

Any number of additional cylinders are added with appropriate inner radius relative to the outer radius of the preceding cylinder to maintain in the space therebetween a cross-sectional area equal to the effective surface area of the speaker driver 12. An appropriate number of cylinders and cylinder lengths establishes a desired acoustic transmission line length within a speaker enclosure.

Use of cap 32 and flange 24 in directing a sound wave from one cylinder to a next must maintain the desired cross sectional area. Accordingly, the specific dimension and shape of such structures, e.g., cap 32 and flange 24, may be designed to maintain such cross sectional area in the travel path provided for sound wave 18.

FIG. 4 illustrates schematically a second embodiment of the present invention including concentric cylinders interconnected to form an acoustic transmission line speaker enclosure 100. In FIG. 4, enclosure 100 includes a basin 114 supported in spaced relation from a floor 142 by means of legs 140. Basin 114 serves as a mounting site for speaker driver 112. A front-traveling sound wave 116 emanates from speaker driver 112 and passes between basin 114 and floor 142. Enclosure 100 includes a central top opening 127. Speaker driver 112 produces a rear-travelling sound wave 118. Sound wave 118 travels within

enclosure 100 and eventually exits enclosure 100 at top central opening 127, i.e., travels from outer cylinders toward a central cylinder defining opening 127.

A central cylinder 120 rests directly above speaker driver 112 and defines at its upper end the top central opening 127. A second cylinder 122 of larger radius relative to cylinder 120 rests concentrically relative to cylinder 120. A third cylinder 124 larger in radius than cylinder 122 rests concentrically relative to cylinders 120 and 122. A fourth cylinder 126 larger in diameter relative to cylinder 124 rests concentrically relative to cylinders 120, 122, and 124. An exterior sidewall cylinder 128 of larger radius than cylinder 126 rests concentrically relative to cylinders 126, 124, 122, and 120. Exterior sidewall cylinder 128 couples directly to and is supported directly at its lower edges by basin 114. The assembly of concentric cylinders 120, 122, 124, 126, and 128 are maintained in fixed relationship by means of interconnecting support elements 130, best seen in FIG. 5.

The interior of cylinder 120 defines a space 121. The interior of cylinder 122 outside cylinder 120 defines a space 123. The interior of cylinder 124 outside cylinder 122 defines a space 125. The interior of cylinder 128 outside cylinder 126 defines a space 129. Cylinders 120, 124, and 128 extend above cylinders 122 and 126.

An annular cap 150 spans the upper edges of cylinders 126 and 128. Similarly, annular cap 152 spans the upper edges of cylinders 120 and 124. As explained more fully hereafter, cap 150 directs sound wave 118 from space 127 into space 129. Similarly, cap 152 directs sound wave 118 from space 125 into space 123. A cap 154, including a convex central portion and concave peripheral portion, closes the lower end of cylinder 122. The concave-convex contour of the inside surface of cap 154 directs sound wave 118 from space 123 into space 121. As may be appreciated, cap 154 must be spaced sufficient distance from cylinder 120 to maintain a desired cross sectional area for the sound wave 118 travel path. An annular cap 156 spans the bottom edges of cylinders 126 and 122, thereby directing sound wave 118 from space 127 into space 125.

In operation, sound wave 118, being blocked by caps 154 and 156, travels outward along basin 114, into space 129, and upward along the periphery of cylinder 126. As sound wave 118 reaches the top of cylinder 126, cap 150 guides sound wave 118 downward into space 127. Sound wave 118 then travels downward along the periphery of cylinder 126 until it encounters cap 156. Cap 156 redirects sound wave 118 into space 125 and sound wave 118 travels upward along the periphery of cylinder 124. Eventually, sound wave 118 travels upward and reaches cap 152 which redirects sound wave 118 downward into space 123. Sound wave 118 then travels downward along the periphery of cylinder 122 until it

encounters cap 154 which directs sound wave 118 into space 121 of cylinder 120. Sound wave 118 then travels upward and exits enclosure 100 at the top central opening 127.

As discussed herein above, the length of transmission line provided in enclosure 150 may be adjusted to meet a particular wave length by manipulation of the overall length dimension of cylinders 120, 122, 124, 126 and 128 in combination with spacing relative to caps 150, 152, 154, and 156. Relative spacing between the caps 150, 152, 154, and 156 and the associated cylinders 120, 122, 124, 126, and 128 must take into account a desired cross sectional area to be maintained along the acoustic transmission line provided by enclosure 100. Also, the relative size, i.e., radius, of cylinders 120, 122, 124, 126, and 128 is calculated as described above to maintain an equal magnitude cross sectional area for the spaces 121, 123, 125, 127, and 129.

FIG. 6 illustrates in more detail the structure of a speaker enclosure according to the embodiment of FIGS. 1-3. In FIG. 6, speaker enclosure 10′ is illustrated in cross section, similar to the cross-sectional view of FIG. 3. Enclosure 10′ receives a 20.32cm (8 inch) speaker (not shown in FIG. 6). Enclosure 10' assumes the "demi-square" shape discussed earlier. Width, both vertical and horizontal in the view of FIG. 6, is 280 mm. The height of enclosure 10′ is dictated by the selected transmission line length, i.e., a function of a specific wave length optimally

coupled to the surrounding air mass. Exterior sidewalls 26, having the above-described "demi-square" cross-sectional shape, are 1.5 mm thick. Interior wall structures, i.e., cylinder 20 and cylinder 30 are only 0.5 mm thick. Cylinder 20 has an 87.50 mm radius and cylinder 30 has a 125.00 mm radius. Cylinder 60, forming the basis for the "demi-square" shape of sidewalls 26 has a 165.00 mm radius. Curved plates 66 have a thickness of 1.5 mm and extend through their curved portion along an arc 150 of 51.39 degrees with a radius of 116.00 mm. The rounded corners of enclosure 10, i.e., the remaining portions of cylinder 60, extend through an arc 152 of 26.09 degrees.

Enclosure 10′ also includes support arms 72 extending radially outward at 4 equi-angularly distributed locations. More particularly, support arm 72a couples cylinder 20 and cylinder 30 while support arm 72b couples cylinder 30 and one of the rounded corners of sidewall 26. Similarly, support arms 72c and 72d extend radially outward toward a next rounded corner of enclosure 10′ with support arm 72c coupling cylinder 20 and cylinder 30 and support arm 72d coupling cylinder 30 and sidewall 26. Support arms 72e and 72f are similarly located relative to a third one of the rounded corners of enclosure 10′. Finally, support arms 72g and 72h extend radially outward in similar fashion to the last one of the rounded corners of enclosure 10.

Thus, an improved acoustic transmission line speaker

enclosure has been shown and described. The speaker enclosure of the present invention utilizes the inherent rigidity and high bending resistance of cylindrical structures to form by concentric relation therebetween, an acoustic transmission line of selected length and cross sectional area. The multi-concentric cylindrical architecture supports simple design strategy to establish a desired length and cross sectional specification; and does not limit the position of the speaker driver, number of cylinders required, or the orientation of sound emanation. The present invention provides a light weight, space saving speaker enclosure using recyclable material. Movement of the rear-traveling sound wave can be arranged either from the outer cylinder towards the central cylinder or from the central cylinder toward the outer cylinder.

While illustrated herein as cylinders, other sleeve-like structures possess inherent high bending resistance and may be used in substation for the more ideal sleeve structure, i.e. a cylinder shaped sleeve. For example the outer walls 126 of the embodiment of FIG. 1 form a sleeve structure having a "demi-square" cross sectional shape.

The speaker enclosures illustrated herein possess an ability to produce extremely smooth low frequency sound waves. Conventional speakers typically cannot reproduce such smooth low frequency sound waves. Accordingly, use of such multi-concentric

cylinder speaker enclosures introduces a new range of audio reproduction, i.e., an ability to produce very smooth low bass frequencies. Production of such smooth low frequency sound waves is a desirable faature for the discerning listener, but such very smooth low frequency sound waves can establish a resonant effect within a listening room. In other words, the speaker enclosures illustrated herein faithfully reproduce sound waves at sufficiently low frequencies to induce cavity resonance in a typical listening room.

FIG. 7 illustrates in block diagram an audio reproduction system 210 located within a given listening room or cavity 212. As may be appreciated, room or cavity 212 possesses a given cavity resonance including a fundamental frequency and associated harmonic frequencies. System 210 includes an audio source 214 presenting right and left audio channels 216a and 216b to a buffer amplifier 218. Buffer 218 amplifies audio channels 216 and presents channels 216 to a series combination of variable frequency notch filters 220, designated individually herein as filters 220a, 220b, and 220c. Notch filters 220 are, for example, variable or tunable notch filters each with a narrow frequency band and high ratio of rejection characteristics. For example, at approximately 30 Hz each filter 220 provides a "notch" or filtering band from 1 to 1.5 Hz wide. Each filter 220 includes three variable resistor trims synchronized to become a variable notch filter tunable to a very narrow frequency band.

Each of notch filters 220 receives channels 216a and 216b, filters a very narrow and low frequency wavelength therein, and provides as output channels 216a and 216b to a next successive component. Notch filter 220a receives channels 216a and 216b from buffer amplifier 218 and passes channels 216a and 216b to notch filter 220b. Notch filter 220b passes channels 216a and 216b to notch filter 220c, and notch filter 220c passes channels 216a and 216b to an equalizer filter 230. Each of notch filters 220a-220c include a corresponding control 222a-222c, respectively, dictating the wavelength filtered from channels 216a and 216b.

Equalizer filter 230 is a conventional equalizer filter providing modification in a plurality of relatively broad frequency bands. Equalizer filter 230 passes channels 216a and 216b to an output driver 232. Output driver 232 provides channel 216a to a speaker enclosure 10a, illustrated schematically in FIG. 7, and channel 216b to a speaker enclosure 10b, also illustrated schematically. Enclosures 10a and 10b correspond to the above-described multi-concentric cylinder acoustic transmission line speaker enclosures. Each speaker enclosure 10a and 10b includes a speaker producing a sound wave 240a and 240b, respectively, within cavity 212. As discussed herein-above, speaker enclosures 10a and 10b faithfully reproduce very low frequency sound waves, low enough to establish a resonance effect within cavity 212. Output driver 232 includes a plurality of

controls 232a according to conventional audio control features, e.g., tone, balance, and volume.

Sound waves 240 enter cavity 212 and provide the desired sound presentation according to audio source 214. Due to cavity 212 resonance, however, certain portions of sound waves 240 tend to build and present a relatively higher volume perception relative to an intended presentation of audio source 214. In particular, certain very low frequency sound waves tend to build within cavity 212.

Thus, system 210 operates generally in the fashion of a conventional audio reproduction system, but incorporates a series of very narrow frequency band notch filters whereby selected narrow low frequency bands in channels 216a and 216b are eliminated by manipulation of controls 222.

In accordance with the present invention, system 210 further includes a 20 Hz to 20 kHz sine wave signal generator 250 providing a sine wave input 252 to output driver 232. Signal generator 250 includes a control 250a dictating the frequency of signal 252. A frequency display 254 coupled to signal generator 250 provides a visual indication of the frequency of signal 252. Thus, by manipulation of control 250a, a user of system 250 injects into cavity 212 sound waves 240 at a given frequency.

System 210 further includes a transducer or microphone 260 coupled to an amplifier 262. Amplifier 262 drives a sound energy display 264. By monitoring sound energy display 264 while manipulating control 250a, the user determines cavity 212 resonance. More particularly, as the user moves control 250a, a range of sound wave 240 frequencies appear in cavity 212. When a frequency coincident with the cavity 212 fundamental frequency enters cavity 212, a relatively greater magnitude sound energy exists within room 212. Accordingly, at such fundamental frequency, sound energy display 264 reaches a maximum value. In this manner, a user of system 210 determines the current fundamental cavity resonance for room 212.

Once control 250a is adjusted to develop sound waves 240 at the fundamental frequency, the user observes frequency display 254. Frequency display 254 then represents the fundamental frequency for cavity 212. The user then adjusts one of notch filters 220, i.e., adjusts a control 222, to correspond to the frequency display 254 presentation. As may be appreciated, calibration provided on control 250 and controls 222 may be coordinated in such manner to allow a user to match a control 222 setting based on a control 250a setting. Alternatively, controls 222 may be calibrated relative to information presentation at frequency display 254. In any case, one of notch filters 220 is adjusted to a given frequency band setting based on the frequency of sine wave injected into cavity 212 and providing a relatively

greater magnitude sound energy therein. In this manner, the user eliminates a narrow frequency band originating from audio source 214.

Further frequency bands, i.e., harmonic frequencies, may also introduce undesirable non-linearity in sound presentation. Such harmonic frequencies may also be detected by further manipulation of control 250a and observation of sound energy display 264. If the user observes additional peak frequencies, i.e., peak values indicated at sound energy display 264, several of notch filters 220 are used to filter corresponding narrow frequency bands. As may be appreciated, more or fewer than three notch filters 220 may be used in a given embodiment of the present invention.

Frequency suppression, i.e., filtering by notch filters 220, would typically by under 250 Hz. In frequencies above 250 Hz, the reverberating interference band is much wider and equalizer filter 230 can be used to smooth any such broad band interference frequencies. The traditional equalizer filter, however, cannot appropriately eliminate cavity resonance due to the extremely low, narrow frequency bands associated with cavity resonance.

FIG. 8 illustrates a second embodiment of the present invention, a digital system 310 providing a more automated method of tuning to a given cavity 312 resonance. In FIG. 8, a digital

audio source 314 provides digital audio signal 316, including right and left stereo channels, to a digital signal conditioning block 318. Digital signal conditioning block 318 drives a variable parameter digital filter 320. As may be appreciated, digital filter responds to parameters applied to establish a selected one or more frequency filter functions. Digital filter 320 output drives a digital-to-analog converter and driver 332. Driver 132 provides an amplified analog version of signal 116, designated 316a, to output transducers 340, i.e., to multi-concentric cylinder speaker enclosures as described herein-above and receiving right and left channels of signal 316a.

As described thus far, system 310 operates generally under conventional digital audio reproduction, but incorporates a variable parameter digital filter 320 in series between digital signal conditioning block 318 and driver 332.

A parameter setting and control block 350 dictates operation of digital filter 320. Parameter setting control block 350 receives a frequency signal 352 and a sound level signal 354. Frequency signal 352 originates from a sine wave generator 356 and arrives via a frequency counter and read out block 358. Further, sine wave generator 356 output applies to digital signal conditioning block 318 as an alternate audio source. In this manner, system 310 injects a sound wave within cavity 312 at a selected frequency.

An input transducer, i.e., microphone, 360 monitors sound waves within cavity 312 and drives an amplifier 362. Amplifier 362 drives a sound level block 364. Sound level block 364 delivers the sound energy signal 354 to parameter setting and control block 350. Microphone 360 may be positioned at a selected point, i.e., an optimum listening point, within room 312 to establish ideal listening conditions at such selected listening point.

System 310 is initialized relative to a given cavity resonance, i.e., to a given set of conditions for room 312, by first injecting a slowly varying frequency sine wave signal into cavity 312. Transducer 360 receives the sound wave and provides, via amplifier 362, representation thereof to sound level block 364. Parameter setting and control block 350 monitors signal 354, representing the magnitude of detected sound energy within room 312, and detects a peak magnitude in signal 354.

Parameter setting and control block 350 associates a given frequency in frequency signal 352 with a peak magnitude indication in signal 354, thereby detecting cavity resonance for room 312. Parameter setting and control block 350 then establishes within digital filter 320 a frequency parameter corresponding to the detected room 312 cavity resonance. Such process may be repeated to detect additional peak magnitude sound level readings in room 312 and associated frequency values. In

this manner, one or more frequency parameters are applied to digital filter 320 to remove from signal 316 narrow frequency bands associated with cavity 312 resonance.

Following initialization, system 310 operates digital audio source 314 in normal fashion, but removes at variable parameter digital filter 320 the detected narrow frequency bands associated with room 312 cavity resonance. Audio reproduction system 310 is thereby tuned to a specific cavity resonance for room 312. As may be appreciated, such tuning may also be invoke manually, by a user following a change of conditions within cavity 312.

Thus, an improved audio reproduction system has been shown and described including ability to tune to a specific cavity resonance. Under the present invention, improved speaker enclosures can produce very low and smooth frequency sound waves including the very narrow low frequency bands associated with cavity resonance. Such frequencies are filtered from an audio signal prior to presentation at the improved speaker enclosures. In this manner, the audio signal is "pre-dampened" at frequencies corresponding to cavity resonance frequencies thereby eliminating sound-build up within the cavity as a function of cavity resonance. The discerning listener thereby enjoys a more faithful, i.e., more linear, reproduction of sound presentation as intended in the original recording.

It will be appreciated that the present invention is not restricted to the particular embodiments that have been described and illustrated, and that variations may be made therein without departing from the scope of the invention as found in the appended claims and equivalents thereof.

CLAIMS

1. A transmission line speaker enclosure having a site for a loud speaker and comprising:

a plurality of concentric sleeves wherein the central one of said sleeves defines an acoustic space having a given cross sectional area and each other sleeve defining an associated acoustic space between itself and the next smaller one of said sleeves and each of which associated spaces is substantially equal in cross sectional area to said given cross sectional area, and wherein adjacent spaces are in communication at adjacent ends thereof such that said sound waves from the speaker travel along the spaces and in opposite directions in adjacent spaces.

2. An enclosure as claimed in Claim 1, including a speaker driver mounting site defining front and rear directions;

wherein one of said sleeves forms a first cylinder positioned relative to said speaker mounting site for receiving at a first end a rear-travelling sound wave and for providing at a second end said rear-travelling sound wave;

another of said sleeves forms a second cylinder concentric to said first cylinder wherein a first end of said second cylinder is adjacent said first end of said first cylinder and a second end of said second cylinder is adjacent said second end of said first cylinder; and

a deflector at said second end of said second cylinder directing said rear-travelling sound wave from said first cylinder into the space part defined by the second cylinder.

3. An enclosure as claimed in Claim 1 or 2, wherein the combined length of said spaces corresponds to a given acoustic transmission line length.

4. An enclosure as claimed in Claim 2, further comprising:

a sleeve adjacent said second cylinder, said sleeve including a first end adjacent said first end of said second cylinder and a second end adjacent said second end of said second cylinder; and

a guide coupling said first end of said first cylinder and said first end of said sleeve

and being spaced from the first end of said second cylinder whereby said guide directs said rear-travelling sound wave out of said second cylinder and into a space between said second cylinder and said sleeve.

5. An enclosure as claimed in Claim 4, wherein said sleeve defines a demi-square shape in cross section, said sleeve including planar wall portions and said enclosure further including support walls for offering bending resistance of said planar wall portions.

6. An enclosure as claimed in Claim 2, and comprising an opening acoustically coupled to said first end of said second cylinder.

7. An enclosure as claimed in any one of the preceding claims wherein said acoustic transmission line is directed from the acoustic space of said central one of said sleeves to an outer-most acoustic space associated with an outer-most one of said sleeves.

8. An enclosure as claimed in Claim 7, wherein said acoustic space of said central sleeve first receives a rear-travelling sound wave of a speaker driver when mounted to said enclosure.

9. An enclosure as claimed in any one of Claims 1-6, wherein said acoustic transmission line is directed from the acoustic space of the outer one of said sleeves to the acoustic space of the central one of said sleeves.

10. An audio reproduction system for a bounded area comprising tuning means including a variable frequency sound source and including a frequency indicator, sound input transducer means arranged for measuring and indicating sound energy within said area and filter means for receiving said audio signal and providing said filtered audio signal, said filter including at least one control dictating a frequency band filtered by said filter and calibrated relative to the output of said frequency indicator.

11. A system as claimed in Claim 10, wherein said filter comprises a notch filter.

12. A system as claimed in Claim 11, wherein said notch filter comprises a tunable notch filter.

13. A system as claimed in Claim 11, wherein said filter comprises a digital variable parameter filter.

14. A system as claimed in any one of Claims 10 to 13, wherein said filter includes a plurality of controls, each dictating a frequency band filtered, each of said controls being calibrated relative to said frequency indicator.

15. A system as claimed in any one of Claims 10 to 14, wherein said variable frequency sound source is a variable sine wave frequency sound source.

16. A method of tuning an audio system to a bounded area comprising the steps:

detecting a cavity resonant frequency of said area;

adjusting a filter to said detected resonant frequency to filter an audio signal at said resonant frequency; and

applying said filtered audio signal to sound transducers within said area.

17. A method as claimed in Claim 16, wherein said detecting step comprises the steps:

injecting into said area a varying frequency sound wave;

monitoring a peak sound energy level in said area; and

identifying said cavity resonate frequency as the frequency of an injected sound wave associated with said peak sound energy level.

18. A method as claimed in Claim 16 or 17, wherein said adjusting step is an automated step wherein said detecting step provides said detected resonant frequency automatically to said applying step.

19. A method as claimed in Claim 16, 17 or 18, wherein said step of adjusting a filter comprises adjusting a notch filter.

20. An audio reproduction system tunable to a bounded listening area, the system comprising:

an audio source providing a first audio signal;

at least one variable frequency notch filter, said notch filter including a control dictating a frequency band filtered thereby, said notch filter receiving said first audio signal, applying a frequency filter function thereto, and providing a filtered audio signal;

a second audio source providing a second audio signal as a variable frequency audio signal;

audio transducers receiving an amplified audio signal and injecting corresponding sound waves into the listening area;

a sound energy detection device responsive to sound waves in the listening area; and

an audio driver receiving said filtered audio signal and said second audio signal whereby said system is tuned to the listening area by first injecting said second audio signal into said area across a range of frequencies, monitoring said sound energy level device to determine a listening area cavity resonant frequency, and applying a representation of said resonant frequency as a control to said notch filter whereupon application of said filtered audio signal to said listening room excludes frequencies at said resonant frequency.

21. An acoustic transmission line speaker enclosure substantially as hereinbefore described with reference to and/or as illustrated in Figs. 1-3, 6 and 4 or 5 of the drawings.

22. An audio reproduction system substantially as hereinbefore described with reference to and/or as illustrated in Figs. 7 and 8 of the drawings.

23. A method of tuning an audio system to a bonded area, substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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Application No:	GB 9700453.5	**Examiner:**	Peter Easterfield
Claims searched:	1 to 9	**Date of search:**	24 March 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H4J (JBA)

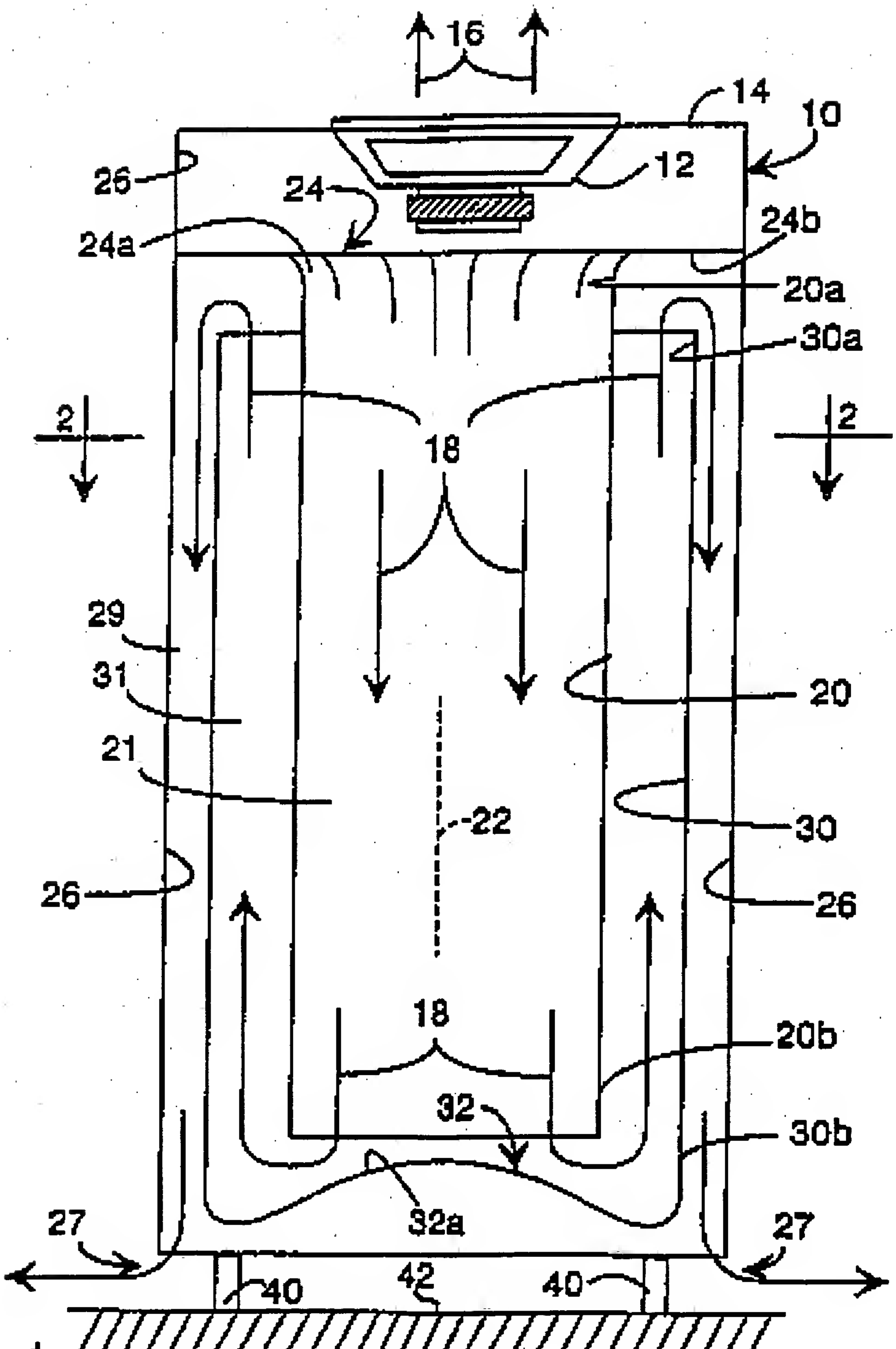
Int Cl (Ed.6): H04R 1/28

Other: Online: WPI, JAPIO, CLAIMS

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 0656732 A	(FORRESTER) see figs. 1 & 4	1,3,7,8
X	GB 0337264 A	(CELESTION et al) see figs. 3 & 4	1,3,7,8
A	US 4298087 A	(LAUNAY)	
X	US 4168761 A	(PAPPANIKOLAOU) see figs 2-7	1,3,7,8
X	WO 95/28064 A1	(HILPUS) see fig. 5	1,2,3,6,9

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.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30b
27
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FIG. 1

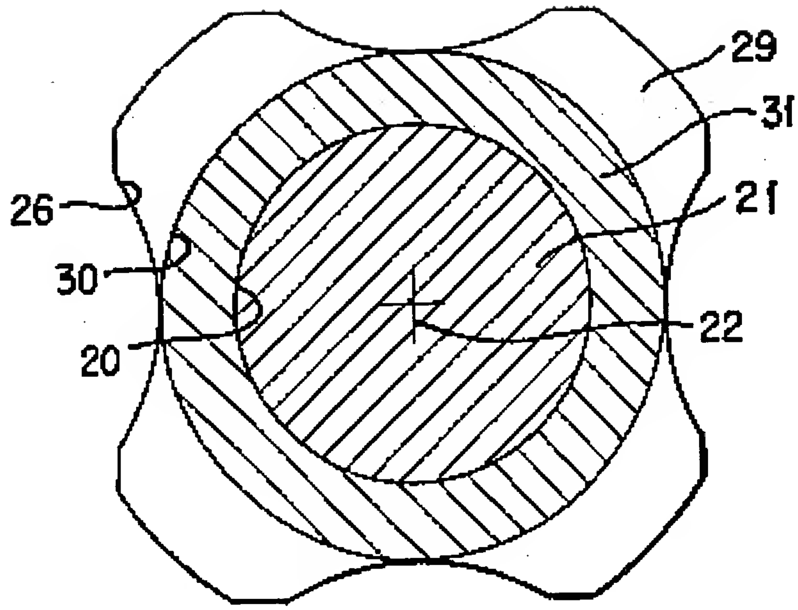
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FIG. 2

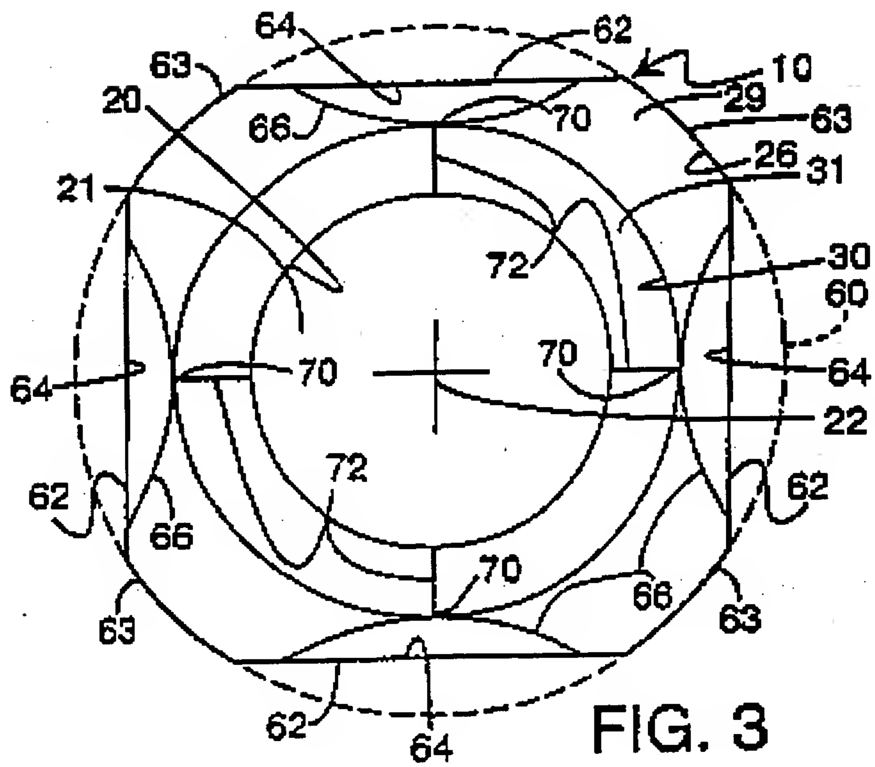
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FIG. 3

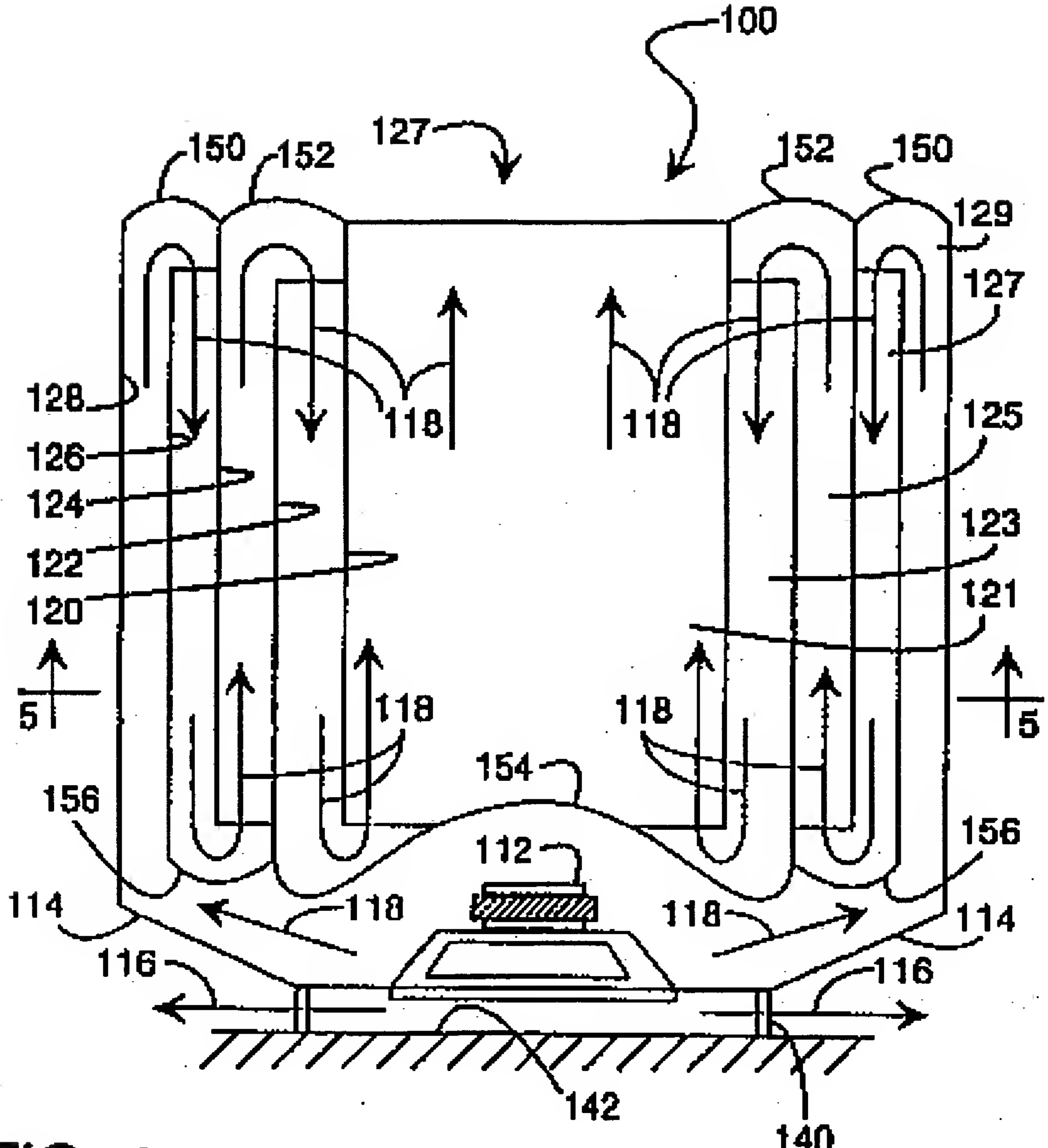
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FIG. 4

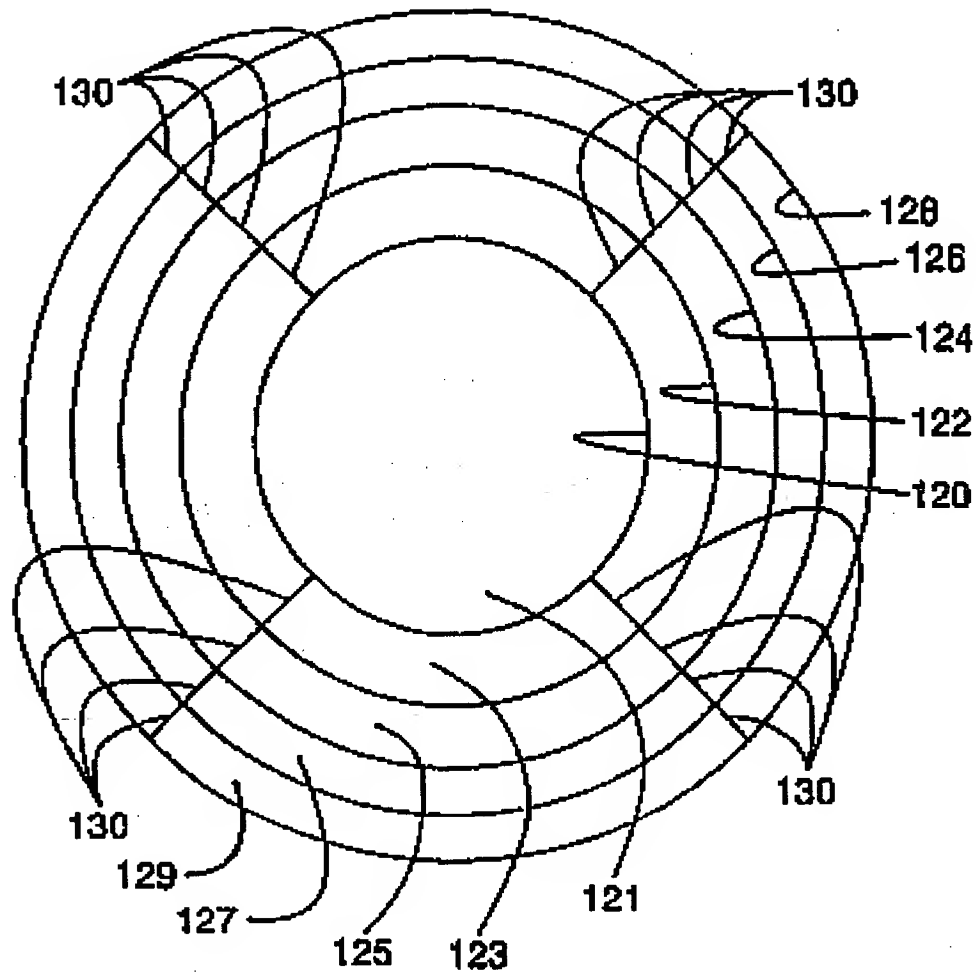

FIG. 5

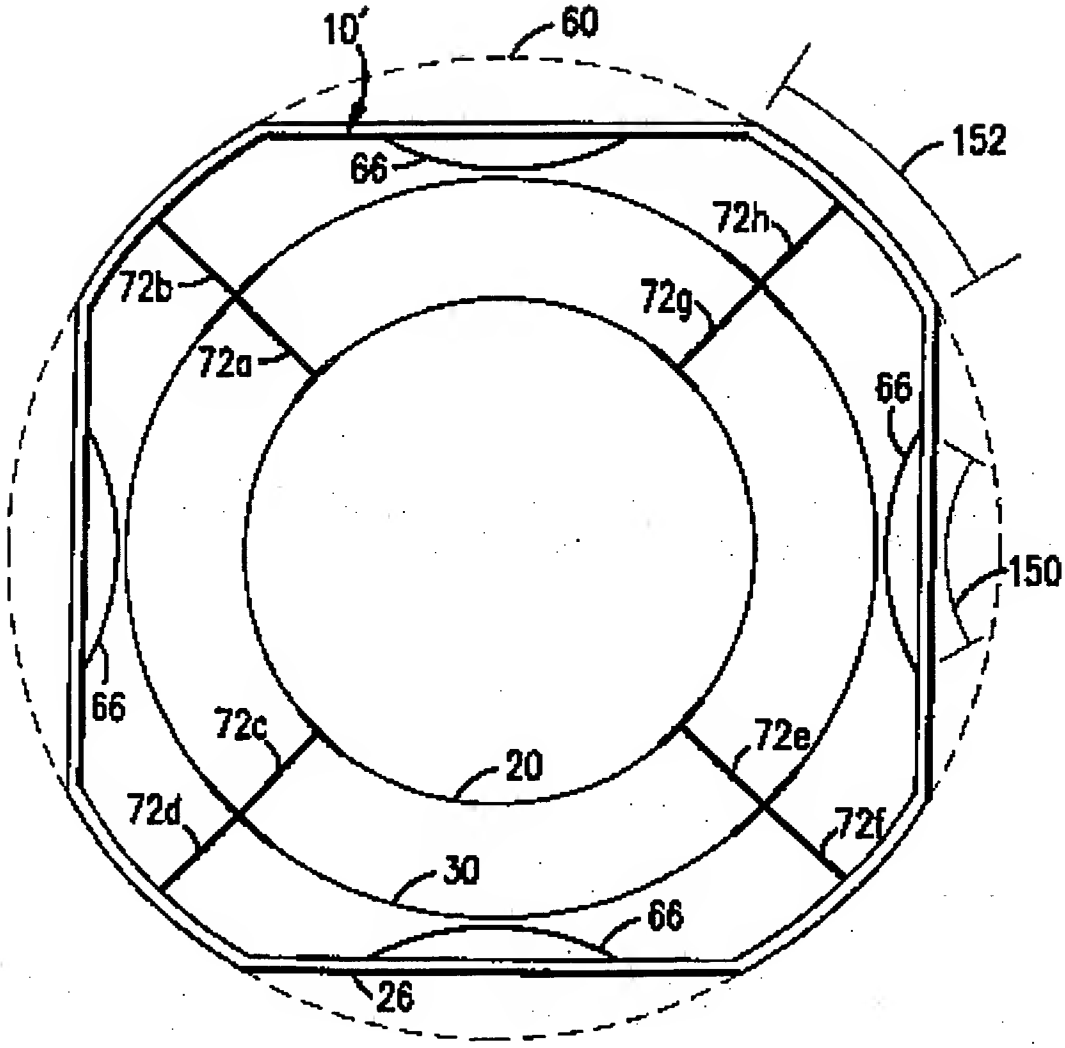

FIG.6

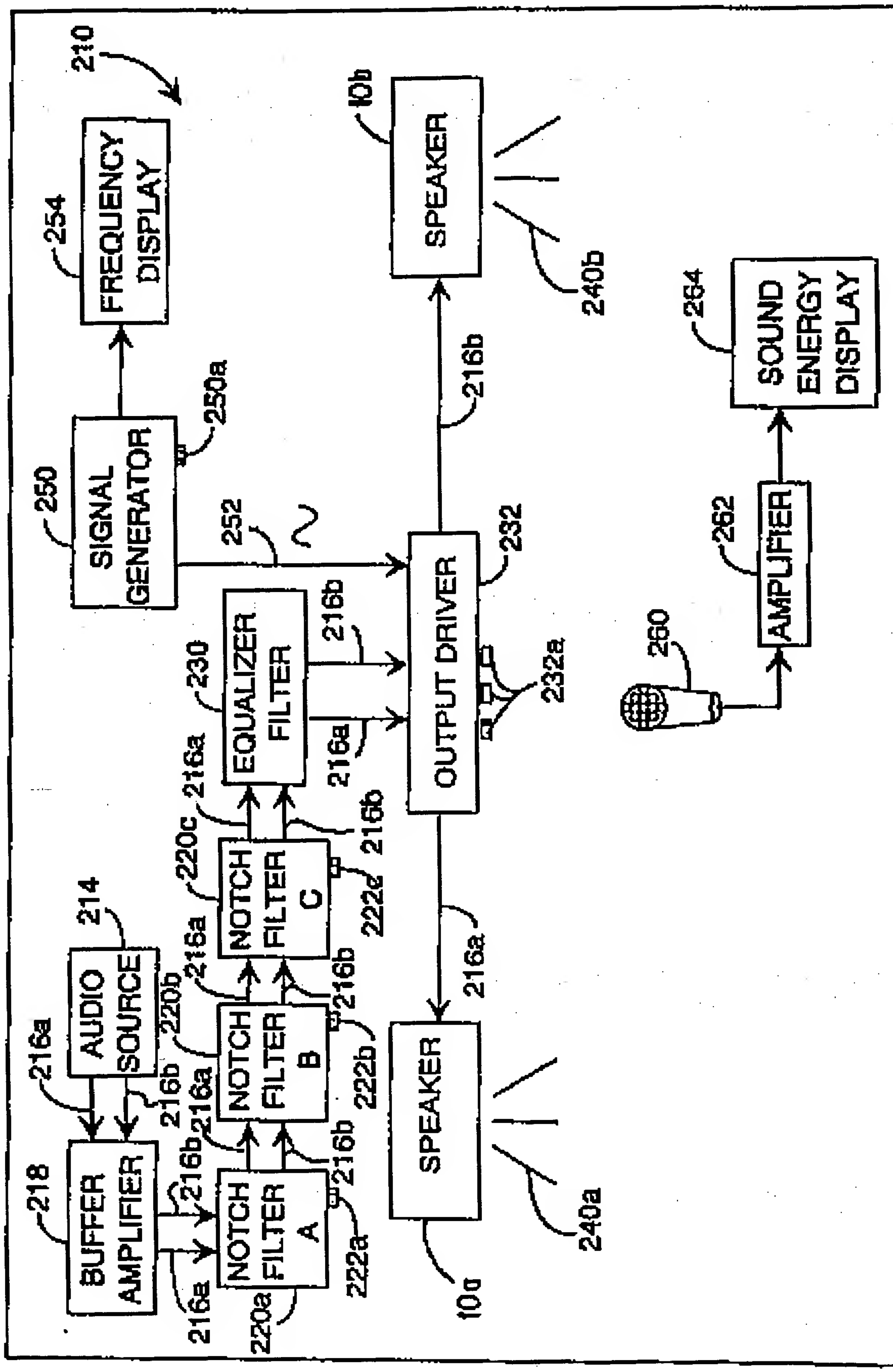
210
212
214
AUDIO SOURCE
216a
216b
218
BUFFER AMPLIFIER
NOTCH FILTER A
NOTCH FILTER B
NOTCH FILTER C
220a
220b
220c
222a
222b
222c
EQUALIZER FILTER
230
OUTPUT DRIVER
232
232a
SPEAKER
10a
10b
240a
240b
SIGNAL GENERATOR
250
250a
252
FREQUENCY DISPLAY
254
260
AMPLIFIER
262
SOUND ENERGY DISPLAY
264

FIG. 7

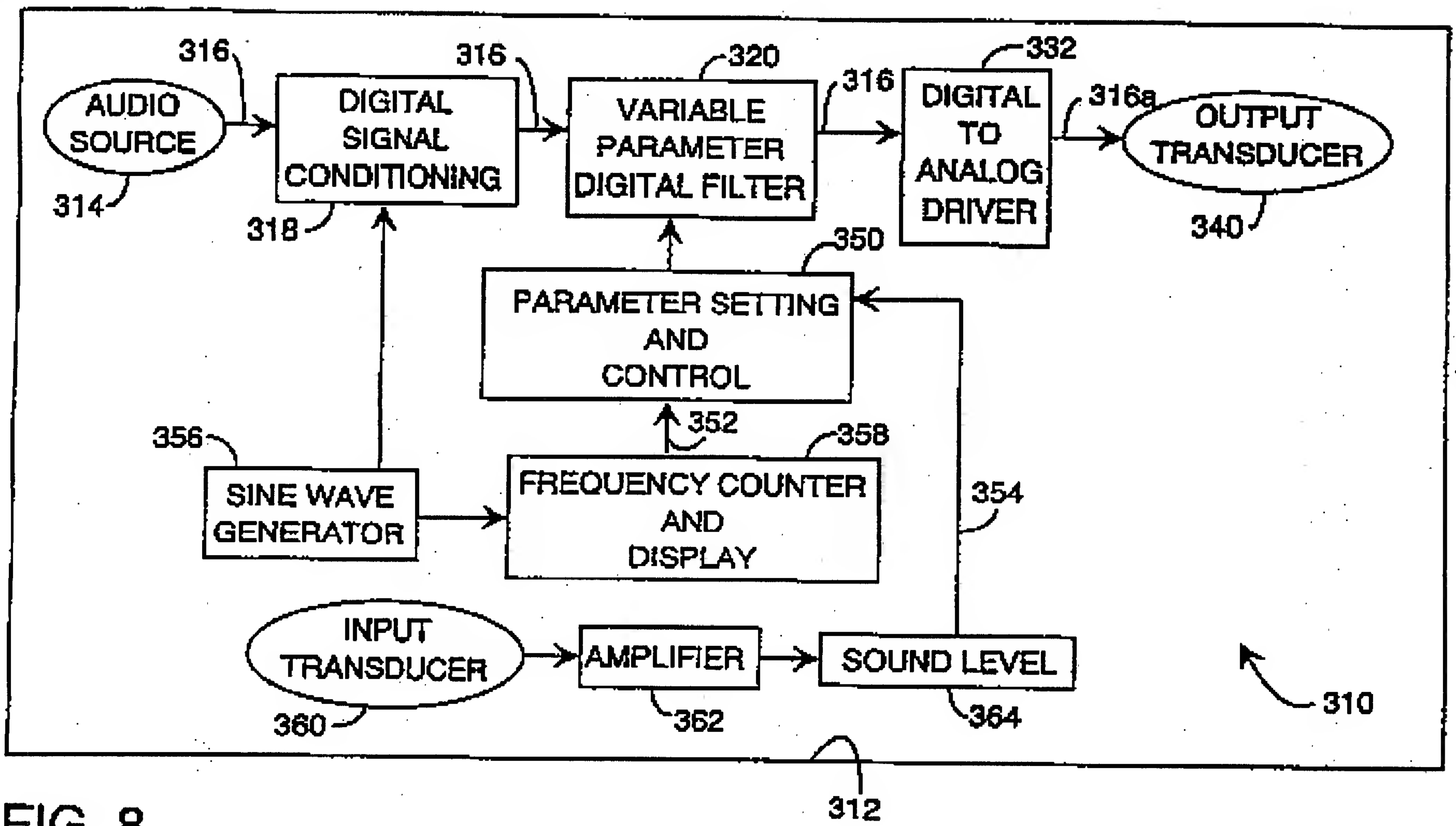
316
316
320
316
332
316a
AUDIO SOURCE
DIGITAL SIGNAL CONDITIONING
VARIABLE PARAMETER DIGITAL FILTER
DIGITAL TO ANALOG DRIVER
OUTPUT TRANSDUCER
314
318
350
340
PARAMETER SETTING AND CONTROL
352
356
358
SINE WAVE GENERATOR
FREQUENCY COUNTER AND DISPLAY
354
INPUT TRANSDUCER
AMPLIFIER
SOUND LEVEL
360
362
364
310
312

FIG. 8